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# Modeling Robot and Crew Interaction

- **Brahms language models multi-agent communications, work scheduling, and life support**
- **Validates and assists mission operations**
- **Increases efficiency, safety, and productivity**

Future NASA missions, such as the human exploration of Mars, will last much longer than the Apollo lunar missions—possibly up to 500 days—and occur at a much greater distance from Earth—too far for "real-time" direction from Earth.

Nevertheless, the mission goals will be more ambitious and consequently more complex. To succeed, the astronauts will need support from robots and software agents that can record, store, and transmit critical navigational and scientific data, monitor life-support systems, and perform other tasks that free the human crew to do higher-level work.

These remote operations will need to be carefully planned. The successful coordination and interaction of humans, robots, and software agents will require new system designs, communication protocols and interfaces. This is a key focus of the CICT Program's Intelligent Systems (IS) Project, which includes scientists who are exploring human-centered computing (HCC). The HCC subproject, managed by Michael Shafto, is developing technologies to improve the performance and productivity of human-computer systems on future NASA missions.

**Modeling the mission**

One of these technologies is the Brahms multi-agent modeling and simulation language and distributed runtime system, developed at NASA Ames Research Center by William J. Clancey, Maarten Sierhuis, Ron van Hoof, and Mike Scott. It can be used to model and run a simulation of the distributed work activities of multiple "agents"—humans, robots, and software agents—coordinating a mission in one or more locations. A Brahms model also includes geography (mission habitat, territory to be explored), objects (spacesuits, laptops, generators, vehicles, rocks), and activities inside and outside of the habitat (meals, email, briefing and planning, getting into or out of a spacesuit, exploring a site, preparing a report).

William J. Clancey, group lead of the Work Systems Design and Evaluation Group at NASA Ames, and Maarten Sierhuis, senior research scientist at Ames, are conducting research on several work-practice environments in which Brahms plays a key role.

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Brahms is being used to model activities at the Flashline Mars Arctic Research Station for possible use in planning Mars missions. The station is located at Haughton Crater, Devon Island, Nunavut, Arctic Canada. (photo: W. J. Clancey)

## Technology Spotlight

### Technology
Brahms multi-agent modeling and simulation language and distributed runtime system—compatible with Windows® 2000, Windows® XP, Linux, SPARC®/Solaris™ and Mac OS® X systems

### Function
Analysis and design of work systems

### Relevant Missions
- Mars Exploration Rover
- Mars Science Laboratory (concept)
- Other Exploration Systems Enterprise missions
- International Space Station

### Applications
- Planning operations, maintenance
- Training teams
- Designing/testing software agents
- Designing habitats

### Features
- Depicts inter-agent communications
- Models time/resource requirements
- Includes communications protocols for multi-agent, mixed-initiative systems
- Automates workflow diagrams
- Patented, industry-standard approach
- Interfaces with formal modeling and verification methods

### Benefits
- Visualize new operations concepts
- Estimate value of adding automation
- Identify communication, command, & control (C3) bottlenecks and risks
- Anticipate human needs and improve resource scheduling
- Design intelligent training systems

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Brahms can be used to model work procedures between astronauts and robots such as the Personal Satellite Assistant (red sphere), a flying robot designed to operate autonomously onboard manned spacecraft in pressurized micro-gravity environments.

**How things really get done**

"We're interested in how the participants or agents actually carry out a planned activity," says Clancey, principal investigator (PI) for the Brahms-based research called *Modeling and Simulating Work Practice*. "A traditional task analysis of work leaves out the informal logistics and circumstantial activities of a collaborative team," he says. Sierhuis, project manager for this research, notes that "participants often need to perform more than one task at a time, hand off parts of a task to others, or provide others with information or assistance at a crucial moment. If any of these acts deviates from a single task's plan, it can dramatically affect all tasks."

A Brahms model can reveal how work actually gets done, and how the participants involve others in their work. Brahms reveals the circumstantial, interactive effects of all the agents on each other, based upon their social beliefs and behaviors—what they know about each other's activities, their intentions, and capabilities, and their understanding of the group norms. These beliefs and behaviors can be based on mission objectives and attributed to robots and software agents, as well as humans. A Brahms model includes these beliefs and behaviors, along with the locations of the participants, their related objects and geography, their activities, and the sequential unfolding of time.

**The social-physical context of work**

As a result, workflow diagrams generated by Brahms are the empirical result of local interactions between agents and representational artifacts. They are not pre-ordained, end-to-end paths created by a modeler.

"Brahms does not model the intricacies of human reasoning and learning, but it does describe the social-physical context that drives reasoning, learning and adaptation," says Sierhuis. "This is why research into actual work practice plays a key role in the development of a successful Brahms model."

**Exploring Mars**

As PI for the project called *Work Practice Simulation Environment for Habitat Design and Scheduling*, Clancey is using Brahms to model the scientific work, scheduling, and daily life of six astronauts at the Flashline Mars Arctic Research Station. The Brahms model integrates the architectural, life-support, and information systems of the habitat (including robots and software agents). Among the early lessons learned from Brahms was the impact of interruptions such as radio communications on enacting planned operations, something that Clancey also noted in the transcripts from Apollo lunar missions.

Clancey says, "The Brahms model will help NASA planners develop the requirements and refine the equipment, procedures, and training they will need for an actual mission to Mars."

Clancey is also the PI, with Sierhuis as project manager, for another Brahms-based project called *Mobile Agents*, which will develop a distributed architecture for simulating and coordinating human-robotic EVA (extra-vehicular activity) teams.

"Manned planetary exploration will require on-site coordination of astronauts, robotic vehicles, and software agents," says Clancey. "To prepare for this, we're implementing a network of Brahms models to monitor and control EVA navigation and scheduling, life support, communications among the crew and with Earth, and the spoken language interfaces to robotic rovers."

**Streamlining ISS operations**

Sierhuis is the PI for a Brahms-based project that studies human-robotic teamwork for future robots aboard the International Space Station (ISS). This project is in collaboration with Jeffrey M. Bradshaw of the Institute of Human and Machine Cognition (IHMC). For this project, Sierhuis is developing a Brahms model and virtual environment for decision support on the ISS to see which tasks could be off-loaded to robot assistants, such as Ames Research Center's Personal Satellite Assistant and Johnson Space Center's Robonaut. The Brahms model is based on data recorded from an actual day of complex operations aboard the ISS, including an EVA. This model will help reduce waiting time, improve situational awareness, and schedule resources more effectively on the ISS.

**Valuable insight**

By modeling how people, robots, and software actually work together, Brahms can provide NASA with valuable insight into potential mission problems and solutions.

*–Larry Laufenberg*

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CICT is part of the NASA Exploration Systems Enterprise's Human and Robotic Technology Theme which represents NASA's commitment to investing in the technologies and capabilities that will make an ambitious and sustainable 21st century space exploration program possible.

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